SAR Sensing of Vegetation Wetness, the first results:

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Abstract

Interception of rainfall by vegetation constitutes a large fraction of total water use and an important feedback mechanism in the hydrological cycle. Research used to be restricted to in situ observations at the patch scale. We present ERS-SAR observations to scale-up local observations. Microwave backscatter increases with the amount of rain water collected on the leaves. At the canopy scale, sensitivity of SAR to vegetation wetness is still present, as well as sensitivity to wetness of the upper soil layer. ERS-SAR data recorded just before and after rainfall are being analysed. Radar backscatter increases for almost all surfaces after rainfall. Preliminary we conclude:
1) ERS-SAR is useful to estimate vegetation wetness;
2) Best results are obtained when soil wetness and reflectivity are known;
3) The satellite determination of vegetation wetness may become more accurate when a larger angle of incidence is used.

Keywords: forest hydrology, vegetation wetness

Introduction

Interception is that part of the rain that falls on the vegetation and evaporates without reaching the ground. Interception is thought to be a significant part of the water budget, especially for aerodynamically rough vegetation, like forests. The significance of interception is caused by the high evaporation rate of wet surfaces. Interception is found to be 10-50% of the precipitation on forest and accounts for even a larger fraction of total water use.

Interception is generally measured as the difference of rainfall outside and inside the forest patch. Due to spatial variability of rainfall, the use of local parameters may result in a severe overestimation of rainfall interception in climate models (e.g. Dolman and Gregory, 1992). Also, the patchy structure of most forests results in an underestimation of the time required to dry up wind exposed forest edges (Klaassen et al, 1996). Finally, direct observations using microwave transmissivity suggest that forest may store a factor two more rain water than calculated from common theory (Klaassen et al., 1997). In the latter study it was recommended to use direct observations of water storage in future interception studies.

Several studies have indicated the sensitivity of ERS-SAR to vegetation wetness. Backscattering of tropical forest has shown to be remarkably constant, suggesting that rainforest can be used to calibrate ERS-SAR (Bernhard and Vidal-Madjar, 1989). However, in the same study backscatter was found to increase by 0.5 dB after a rain shower. Dobson et al. (1991) even found increases of 2-3 dB at C-band backscattering during a break between rain showers for several coniferous and northern hardwood forest species. For low vegetation an increase of 4 dB was found. The sensitivity of ERS-SAR to vegetation wetness was further confirmed by Brown et al. (1993), Rignot et al. (1994) and Pulliainen et al. (1996). In these studies, the sensitivity to vegetation wetness was only noticed as a side effect.

The aim of the present study is to analyse the potential of ERS-SAR for rainfall interception studies. We expect that ERS-SAR may improve the understanding of spatial variability of interception and thus improve the simulation of interception in climate models. Moreover, ERS-SAR may increase our understanding of the influence of species composition and leaf area index on rain water storage. Finally, we may expect that the drying time after the last shower varies over the area covered by the SAR image, and thus we may gain a better insight into the drying of vegetation after rainfall.

Theory

The sensitivity of ERS-SAR to vegetation wetness was theoretically investigated. Special emphasis was placed on leaf scale processes. Assuming a water film of 0.2 mm on a small leaf of 0.2 mm thickness and 60% gravimetric water content the backscatter would increase with 8 dB due to leaf wetness. A leaf film of 0.2 mm would result in a water storage of 1 mm for a forest with leaf area index 5, and may be taken as a common value for many forests. Especially on young leaves, however, rain water is not stored as a film, but as droplets on the leaves. Fortunately, as long as the leaf dimensions are small as compared to the radar wavelength, it is mainly the amount of water, and not the spatial distribution, that accounts for backscatter. For coniferous vegetation with small needles, it is not the individual needle that should be taken as the basic backscattering entity, but the shoot with a cloud of needles. In that case the backscatter is slightly less sensitive to vegetation wetness, as the emissivity of the basic entity is already increased by the presence of the shoot.

It is concluded that at the leaf scale C-Band backscatter is increased by up to 8 dB by stored rainwater. The sensitivity of backscatter to water storage may depend on leaf type but should hardly depend on the distribution of water on the leaves.

To scale up the backscatter of leaves to canopy backscatter, we used the model of Karam et al. (1992). A very dense canopy with Leaf Area Index (LAI) = 10 implies that almost all backscatter arises from the canopy. Backscatter by the wet canopy is increased by 1 - 2 dB. The values are smaller as compared to single leaves because increased absorption by wet leaves results in less reflection from deeper layers in the canopy.

A medium dense canopy with LAI = 5 results in a contribution of the soil to the total backscatter. Table 1 shows the simulation results for a soil with 50% sand and a varying percentage of water. Other input parameters are:

Leaf radius: 2.5 cm

Leaf thickness: 0.2 mm

Gravimetric leaf water content: 60%

Thickness water on wet leaves: 0.2 mm

Roughness of soil: 2 cm

Soil water (% water)	**dry**	**wet**	**wet-dry**
0	-9.9	-8.2	1.8
10	-9-5	-8.2	1.4
20	-9-2	-8.1	1.1
30	-9.0	-8.1	0.8
40	-8.8	-8.1	0.7
50	-8.7	-8.1	0.5

Table 1: Backscatter (in dB) of Wet and Dry Forest

Theoretical analysis indicates that it is possible to estimate vegetation wetness using ERS-SAR. The reflectivity in wet conditions arises almost entirely from the canopy. A dry canopy results in a larger transmissivity, and some sensitivity to soil conditions. The calculations suggest that it would be advantageous to use three recordings: 1) wet canopy and wet soil; 2) dry canopy and dry soil; and 3) dry canopy and wet soil.

From the theoretical analysis it is recommended to use a measurement method that diminishes soil reflectivity. The following strategies might improve the estimation of vegetation wetness:

1) Use a higher frequency with stronger attenuation in the canopy

2) Use cross polarization: Karam's model suggests little cross-polarized

backscatter from the soil and 2 dB increase of cross-polarized backscatter from wet vegetation

3) Use a larger observation angle with the vertical, thus increasing the length of the

radar beam through vegetation and decreasing the backscatter of the soil in the direction of the observation.

Data

Data from the ERS Tandem mission are used for experimental validation. Image pairs were selected with one image recorded with dry vegetation and the other with wet vegetation. Detection of the change of backscatter between these images would experimentally show the sensitivity of ERS-SAR to vegetation wetness. Data were selected from an area in the North of the Netherlands, where two field campaigns on rainfall interception were executed.

Figure 1 presents the very first result. It shows the difference in reflectivity between 7 and 8 september 1995.

It was the end of a dry summer with only 23 mm precipitation in the last month before the first observation. So the observation was made in dry conditions. A showery cold front with 7 mm rain passed at the end of the afternoon followed by drizzle in the early night. It can safely be assumed that the vegetation was still wet the following morning at 10:34 UTC when the second observation was made. Air temperature was 15 ^{0}C, mean wind velocity 5 m/s with a heavy overcast sky in the period between the recordings.

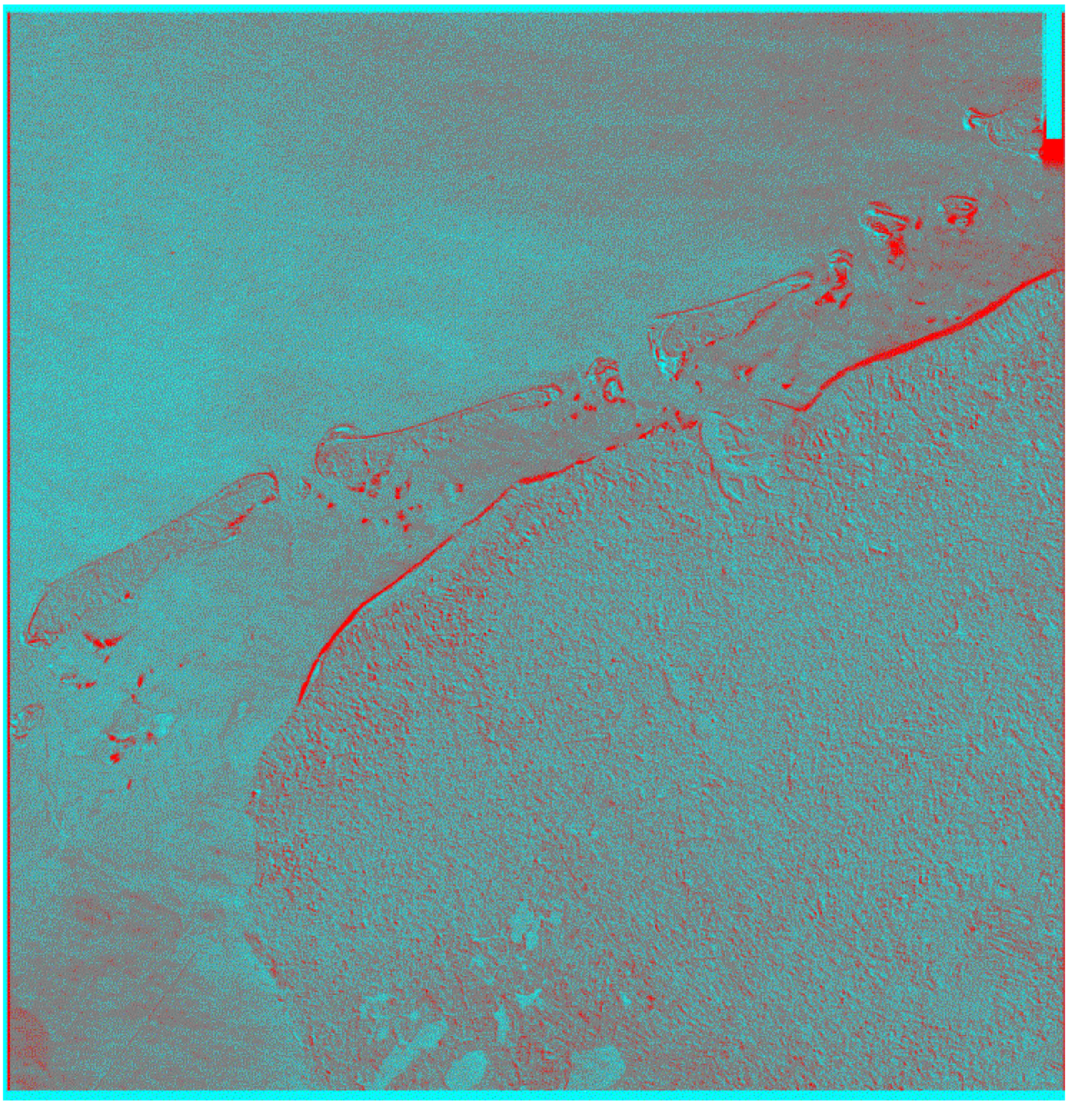

Figure 1: Difference in ERS-SAR reflectivity between 7 and 8 september 1995 in the Wadden Sea area. Surface conditions were dry on 7 september and wet on 8 september. Blue colors indicate more reflectivity on the first day and red colors indicate more reflectivity on the wet day. See text.

Results

Figure 1 shows that reflectivity increases with surface wetness, see table 2

Surface	**Wet - Dry (dB)**
rain above sea	-2
open water	0
grassland	1
forest	1.5
arable land	2
salt marsh	9.5

Table 2: Difference in reflectivity between wet and dry surfaces

The largest increase in reflectivity is found in salt marsh. This is caused by flooding of the sea and shows that soil wetness may account for differences in reflectivity of the order of 10 dB. For arable land the result for arable land is a rough estimate as it is averaged between bare soil and vegetated surfaces. The results for grassland and forest agree well with the theoretical result of table 1. However, the increase for grassland is smaller than for forest, in disagreement with Dobson et al (1991). We suggest that the relatively small increase for grassland is caused by the wet soils that prevail in this part of the country, even in dry summers. In contrast, forests are usually situated on the dryer soils and this may explain the larger increase of reflectivity due to wetting of the forest.

We plan to continue this study by analysing ERS-SAR recordings from other dates and places. Moreover we will try to use these data in a more quantitative way to estimate the amount of water on vegetation, the areal extend of wetting and the drying time after rainfall.

Conclusions

The theoretical analysis shows that ERS-SAR has the potential to measure vegetation wetness. However, when analysing radar data, care should be taken to distinghuish between soil and vegetation wetness. Soil influences are diminished using a larger angle of incidence of the radar beam.

Empirical evidence agrees with the modelling effort that ERS-SAR is indeed sensitive to vegetation wetness. Further study is planned to analyse the potential of ERS-SAR for quantitative studies on rainfall interception by vegetation.

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